

**DOPPLER CORRECTED COMMUNICATIONS RECEIVER AND
METHOD OF REMOVING DOPPLER FREQUENCY SHIFT**

Field of the Invention

This invention relates to communications receivers, and more particularly, this invention relates to removing Doppler frequency shift in CDMA 5 communications receivers.

Background of the Invention

Cellular telephone and mobile telephone systems are becoming more commonplace. In third 10 generation mobile systems that are currently being developed, the mobile system must support a mobile speed up to 500 Km/Hr, which incurs a large Doppler frequency shift. Many of these mobile systems use rake receivers for enhanced multipath discrimination and 15 other advantages. These receivers are used with spread spectrum communication signals, such as a code division multiple access (CDMA) communication system, where the rake receiver performs continuous, detailed measurements of multipath characteristics to combat 20 selective fading. This can be accomplished in some rake devices by detecting a signal from each path individually, using correlation methods and algebraically combining echo signals into a single detected signal. Most rake receivers use rake 25 "fingers" or sections, which combine signals received from the various paths. The rake fingers can be analogized to matched filters, where path gains of each

"finger" work similar to matched filter taps. Examples of various rake receivers and rake "finger" structures are disclosed in U.S. Patent Nos. 5,659,573; 5,910,950; 6,085,104; and 6,163,563.

5 As noted before, the mobile systems support high speeds are subject to Doppler frequency shift. One conventional method for solving and eliminating Doppler frequency shift within spread spectrum receivers and typically rake receivers, is the use of
10 channel estimation to estimate Doppler frequency shift. This type of system, however, requires a complex filter structure and an optimum filter, such as Wiener filter, that is not realizable in many circuits.

15 Summary of the Invention

It is therefore an object of the present invention to provide a method and a receiver structure of removing the Doppler frequency shift in an optimum and realizable manner.

20 In accordance with the present invention, a novel architecture of a rake receiver uses differential detection to remove the Doppler frequency shift. A spread spectrum communications signal has a dedicated physical channel that carries the data and common pilot
25 channel that carries the pilot and is received within a rake receiver. The Doppler change in frequency is estimated using the common pilot channel. The Doppler error is cancelled within the dedicated physical channel using the estimated Doppler frequency change.

30 The receiver is, in one aspect of the present invention, a rake receiver and the spread spectrum communications signal comprises a code division multiple access (CDMA) communications signal. The Doppler change in frequency is estimated, in one aspect
35 of the present invention, by multiplying a

channelization code into respective in-phase (I) and quadrature (Q) channels, summing over a symbol period, and sampling to obtain respective I and Q sampled values. To estimate the Doppler frequency shift, the
5 sampled values are phase shifted, and an arc tangent taken of I and Q sampled values.

In yet another aspect of the present invention, the method comprises the step of estimating sine and cosine values of the estimated Doppler
10 frequency shift to be multiplied within the dedicated physical channel. This channel can be split into I and Q data channels that receive an estimated Doppler change in frequency within respective I and Q Doppler estimation channels.

15 A communications receiver of the present invention includes a pilot channel rake section having I and Q Doppler estimation channels for estimating the Doppler change in frequency based on a common pilot channel. A data channel rake section has I and Q data
20 branches that remove the Doppler frequency shift and have data recovered. Each I and Q data channel includes a delay circuit for receiving respective I and Q signals split from the spread spectrum communications signal at baseband and sine and cosine branches for
25 receiving and multiplying into the sine and cosine branches the estimated Doppler change in frequency.

An addition circuit adds together any multiplied product received from respective sine and cosine branches. An integrator introduces a spreading
30 factor when canceling Doppler error. Each I and Q Doppler estimation channel includes a mixer for receiving the spread spectrum communications signal at baseband and a channelization code. Each I and Q Doppler estimation channel also includes an integrator
35 and sample and delay circuit, including a phase

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shifter. Each sample and delay circuit includes a multiplier for receiving a delay signal from the respective other I or Q Doppler estimation channel.

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Brief Description of the Drawings

Other objects, features and advantages of the present invention will become apparent from the detailed description of the invention which follows, when considered in light of the accompanying drawings
10 in which:

FIG. 1 is a high level block diagram of a Doppler-corrected rake finger structure used in a communications receiver of the present invention.

15 FIG. 2 is a high level flow chart illustrating basic operation of the method used with communications receiver of the present invention.

FIG. 3 is a detailed block diagram of the Doppler-corrected rake finger structure shown in FIG. 1.

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Detailed Description of the Preferred Embodiments

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments 25 of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, 30 and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

The present invention advantageously removes the Doppler frequency shift in a communications 35 receiver, such as the illustrated rake receiver 10,

using differential detection. As is well known, third generation mobile systems must support mobile speeds up to 500 Km/Hr, which incurs a large Doppler frequency shift. The architecture and circuit of the present invention uses differential detection and removes the Doppler frequency shift in the rake receiver **10**.

As is well known, different spread spectrum communications signals can be used with rake receiver structures. In the present illustrated aspect of the invention, the type of spread spectrum communications signal is a direct sequence spread spectrum signal, such as a code division multiple access (CDMA) communications signal. As is well known, in the 3G wideband CDMA (W-CDMA) system, it includes a common pilot channel and dedicated physical channel, such as for data, e.g., a data channel. The present invention uses mathematical derivations and associated algorithms with the common pilot channel to estimate the Doppler frequency and use that Doppler frequency estimation to remove, i.e., cancel, the Doppler frequency for the dedicated physical channel of the wideband code division multiple access (W-CDMA) communications signal.

As shown in FIG. 1, a high level block diagram of a rake receiver **10** having a Doppler-corrected rake finger structure is illustrated. The signal is down converted **10a** and descrambled **10b**. The signal is next split at baseband via a mixer and phase shift circuit **11** into in-phase (I) and quadrature (Q) components and into in-phase (I) first and second paths and quadrature (Q) first and second paths. The first path includes a pilot channel rake section **12** having I and Q Doppler estimation channels **14,16** for estimating

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the Doppler change in frequency based on a common pilot channel.

A data channel rake section **18** has two parts **20,22**, which receive the data from the dedicated physical channel and cancels the Doppler frequency shift. To have data recovered, the rake section **12** receives the pilot from the common pilot channel and uses it to estimate the Doppler frequency shift. Each I and Q data channel **20,22** includes a delay circuit **24** for receiving respective I and Q signals split from the spread spectrum communications signal at baseband.

Sine and cosine branches **26,28** have mixers **30,32** that receive and multiply at the mixers **30,32** the Doppler frequency change in frequency that is estimated from the pilot channel rake section **12**. The sine branch **26** includes phase shift circuit **34** for shifting the delayed signal 90° , imparting the necessary phase change for the sine branch. An addition/subtraction circuit **36** adds and subtracts the necessary multiplied product received from respective sine and cosine branches **26,28**. A mixer **38** receives the channelization code and an integration circuit **40** to cancel the Doppler error over every symbol. It integrates over one symbol time, which is equal to the spreading factor multiplied by the chip time ($SF \times T_c$).

Each I and Q Doppler estimation channel **14,16** includes a mixer **42** for receiving the I and Q portions of the spread spectrum communications signal at baseband and a respective I, Q channelization code. Each I and Q Doppler estimation channel also includes an integrator **44**, a sample circuit **46**, and a delay circuit **48**, including a phase shifter **50** and multiplier and add/sum circuit **52**. A divide circuit **53** for the produced A_k and B_k signal components is subject to an

arc tangent function in arc tangent circuit **54**, together with a sine and phase circuit **56** to produce the estimated sine and cosine Doppler frequency correction components. Further details of the circuit 5 are shown and explained with reference to FIG. 3 below.

- FIG. 2 illustrates a high level flow chart of the sequence of steps of the present invention, where a spread spectrum communication signal is received in a receiver (block 100). The spread spectrum 10 communication signal has a dedicated physical channel and common pilot channel. A channelization code is multiplied (mixed) into respective in-phase (I) and quadrature (Q) channels (block 102), summed over a symbol period (block 104) and sampled to obtain 15 respective I and Q sampled values (block 106). At the same time, on a parallel path, the channelization code I/Q is mixed for the pilot channels (block 108). These values are summed over the symbol period (block 110) and then sampled to obtain I/Q samples (block 112). 20 These values are phase shifted (block 114) and the Doppler frequency shift is estimated (block 116). This value is used to cancel the Doppler frequency error (block 118) together with the samples to obtain the I/Q sampled values (block 106).

- 25 For purposes of explanation, a description of the algorithm used with differential detection in the rake receiver design shown in FIGS. 1 and 3 is set forth in detail, followed by a detailed description of the circuit shown in FIG. 3 that implements the method 30 and algorithm.

As noted before, in the DL of a W-CDMA communication signal, a common pilot channel (CPICH) exists and is advantageously used in the present invention. A mathematical derivation of the present 35 invention is possible by using the common pilot channel

to estimate the Doppler frequency and use that estimation to remove the Doppler frequency for the dedicated physical channel (DPCH). As is known, the communication signal is received, downconverted and 5 descrambled. In this description, $R(t)$ is the signal after the down conversion and descrambling for each path.

$$r(t) = \sqrt{2}p\alpha(t)a_I(t)C_1(t)\sin(2\pi\Delta f t + \theta(t)) + n_I(t) + \sqrt{2}p\alpha(t)a_Q(t)C_Q(t)\cos(2\pi\Delta f t + \theta(t)) + n_Q(t)$$

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Equation 1

In this equation, p is the signal power. $C_1(t)$ and $C_Q(t)$ are the channelization codes for the I 15 and Q channels respectively, while $\alpha(t)$ is the fading amplitude. $\theta(t)$ is the phase error and $\Delta f = f_d + f_e$ is the sum of Doppler shift frequency and frequency error due to an imperfect down conversion.

The system uses the common pilot to estimate 20 the frequency error. $a_I(t)$ and $a_Q(t)$ are symbol data. It should be understood, however, that the system can be extended to using the pilot pattern in the dedicated common control physical channel also.

The channelization code in the I and Q 25 channels respectively are attached (in DL W-CDMA, they are the same), and they are summed over the NT_c , where N is the symbol period. ($N=256$ in the common pilot channel in this non-limiting example). The signal is sampled. The sampled values I_k and Q_k are given as 30 follows. For the explanatory purposes in the following equation, the noise terms are ignored.

$$I_k = \int_{(k-1)NT_c}^{kT_c} \sqrt{2p} \alpha(t) a_I(t) \sin(2\pi\Delta f t + \theta(t)) = \sqrt{2p} \alpha_k a_{Ik} [\cos(2\pi\Delta f(k-1)NT_c + \theta) - \cos(2\pi\Delta f k NT_c + \theta)]$$

$$Q_k = \int_{(k-1)NT_c}^{kT_c} \sqrt{2p} \alpha(t) a_Q(t) \cos(2\pi\Delta f t + \theta(t)) = \sqrt{2p} \alpha_k a_{Qk} [\sin(2\pi\Delta f k NT_c + \theta) - \sin(2\pi\Delta f(k-1)NT_c + \theta)]$$

Equation 2

5 In Equation 2, it is assumed that $\alpha(t) \approx \alpha$ and $\theta(t) \approx \theta$ since $N \cdot T_c \ll 1/f_d$ (flat fading). Moreover, by taking a 90 degree phase shift of I_k and Q_k , the following is obtained:

$$10 \quad I_k^{90^\circ} = \sqrt{2p} \alpha_k a_{Ik} [\sin(2\pi\Delta f k NT_c + \theta) - \sin(2\pi\Delta f(k-1)NT_c + \theta)] \\ Q_k^{90^\circ} = \sqrt{2p} \alpha_k a_{Qk} [\cos(2\pi\Delta f k NT_c + \theta) - \cos(2\pi\Delta f(k-1)NT_c + \theta)]$$

15 Equation 3

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These quantities are used to estimate the Δf :

$$20 \quad A_k = I_k Q_{k+1} - Q_k I_{k+1} = \sin(2\pi\Delta f(2NT_c)) - 2\sin(2\pi\Delta f NT_c) = \\ 2\sin(2\pi\Delta f NT_c) [\cos 2\pi\Delta f NT_c - 1]$$

$$B_k = I_k Q_{k+1}^{90^\circ} - Q_k I_{k+1}^{90^\circ} = 2\cos^2(2\pi\Delta f NT_c) - 2\cos(2\pi\Delta f NT_c) = 2\cos(2\pi\Delta f NT_c) [\cos 2\pi\Delta f NT_c - 1]$$

25 Equation 4

From Equation 4, the arctan is used to obtain an estimate of Δf :

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$$2\pi\Delta f \hat{=} \frac{1}{NT_c} \tan^{-1} \left(\frac{A_k}{B_k} \right)$$

5

The Δf estimate is used to remove the frequency error due to the Doppler shift and imperfect down conversion.

10 Let $r_1(t)$ and $r_Q(t)$ represent the in-phase and quadrature part of the received signal for another rake finger that is used to receive the data channel, such as shown in FIGS. 1 and 3. Therefore:

$$15 \quad r_1(t) = \sqrt{2p\alpha(t)} a_1(t) C_1(t) \sin(2\pi\Delta ft + \theta(t)) + n_1(t)$$
$$r_Q(t) = \sqrt{2p\alpha(t)} a_Q(t) C_{Q1}(t) \cos(2\pi\Delta ft + \theta(t)) + n_Q(t)$$

Equation 6

$$20 \quad x_1(t) = r_1(t) \cdot \cos 2\pi\Delta ft - r_1^{90^\circ}(t) \cdot \sin 2\pi\Delta f = \sqrt{2p\alpha(t)} a_1(t) C_1(t) \sin(\theta(t)) + n_{x1}(t)$$

$$x_Q(t) = r_Q(t) \cdot \cos 2\pi\Delta ft - r_Q^{90^\circ}(t) \cdot \sin 2\pi\Delta f = \sqrt{2p\alpha(t)} a_Q(t) C_Q(t) \cos(\theta(t)) + n_{xQ}(t)$$

Equation 7

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From Equation 7, the frequency-corrected data is obtained. The phase error $\theta(t) \approx \theta$ is over the symbol period. Therefore, it can be alleviated using the simple channel estimation.

In the DL of W-CDMA, because the spreading factor (SF) is not changing dynamically, the channelization code is multiplied for the channel and accumulated over $SF \cdot T_c$, i.e., the symbol period.

35 FIG. 3 shows a more detailed block circuit diagram of the rake finger structure shown in FIG. 1. There is no illustrated acquisition and tracking

circuit as would typically be used in a rake receiver. The phase error introduced due to the imperfect acquisition and tracking is considered in $\theta(t)$, which can be alleviated via simple averaged channel
5 estimation. There is a $2NT_c$ delay in the other fingers, because it takes $2NT_c$ samples to obtain $I_k, I_{k+1}, Q_k, Q_{k+1}$.

As illustrated, the spread spectrum communications signal after down conversion is received within the RF receive circuitry **11** where it is split
10 into two signals and mixed in mixers **200, 201** with signals produced from the appropriate sine ($2\pi f_c T$) and 90° phase shift circuits **202, 203** to form the respective I and Q baseband signals. These signals, in turn, are again split as described before.

15 As illustrated, on the second path for the in-phase (I) and quadrature (Q) portions, the signal is delayed by the delay circuit **24** and then split into sine, cosine branches, where on sine branch it is rotated 90° . After mixing, the two signals enter the
20 addition/subtraction circuit **36** and are combined and mixed with the channelization code in mixer **38** for the data channel and integrated over $SF \cdot T_c$ period of time. The signal is sampled at circuit **210** to form the Doppler cancelled data.

25 As to the first path of the I and Q signal, the signals enter the mixers **42** where the respective I or Q channel components are mixed with the pilot channelization code and then integrated, sampled, delayed and 90° phase shifted. Part of the sampled
30 signal is cross-coupled into a pair of mixer/multipliers **212** that receive signals from the delay circuit. The signals from the delay circuit also are cross-coupled into a second pair of mixer/multipliers **214** that receive the 90° phase shift

- signal. These are then received within respective addition/subtraction circuits **216** producing signals A_k , B_k , which are received and divided by the dividing circuit **53**. The arc tangent is taken in circuit **54**.
- 5 The mixer/multiplier **230** receives the signal and mixes input $1/NT_c$, which product is received within a sine logic circuit **232** where the estimated sine Doppler cancellation signal and the cosine cancellation signal (after entering the 90° phase shift circuit **234**) is
- 10 obtained. These resultant values are used to cancel the Doppler as described above.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented 15 in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that the modifications and embodiments are intended to be included within the 20 scope of the dependent claims.